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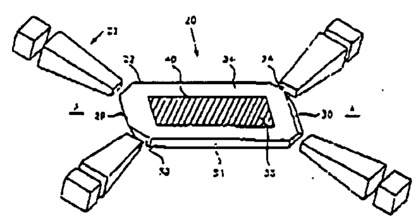
[54] 发明名称 一种用于板条的角泵浦方法及其固体激光增益模块

[57] 摘要

一种用于板条的角泵浦方法及其固体激光增益模块，其主要技术方案是采用角泵浦结构，该结构是将泵浦光源放置在板条的角部位置，使泵浦光从板条的角部平面入射到板条内部。板条中心包括一个或多个掺杂区域，四周键合为不掺杂区域。由于全反射，可以使大部分泵浦光被限制在板条内部进行多次吸收，因而可以获得相当长的吸收长度和较高的吸收效率，从而提高激光器的总体效率。板条采用中心掺杂，四周不掺杂的结构，保证了泵浦光在板条中心被吸收，可以降低热透镜效应和应力双折射效应，避免板条的变形；更重要的是能够达到更高的泵浦功率密度和更好的泵浦均匀性，适用于低吸收系数的固体激光介质。本发明可应用于高功率固体激光器以及固体激光放大器中。



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权 利 要 求 书

1. 一种用于板条的角泵浦方法，其特征在于：该方法使泵浦光从板条的角部 到板条内部。

2. 按照权利要求1所述的方法，其特征在于：板条角平面对泵浦波长高透，板条侧平面对泵浦波长高反。

3. 按照权利要求1或2所述的方法，其特征在于：激光光束在板条内的两个反射面之间沿着之字形光路传播。

4. 实施如权利要求1所述方法的一种角泵浦固体激光增益模块，包括由固体激光材料构成的具有入射面和出射面的板条以及泵浦光源，其特征在于：采用角泵浦结构，该结构是将泵浦光源放置在板条的角部位置，其泵浦光从板条的角部平面入射到板条内部。

5. 按照权利要求4所述的角泵浦固体激光增益模块，其特征在于：所述的板条具有四个角面。

6. 按照权利要求4所述的角泵浦固体激光增益模块，其特征在于：所述板条由中心部分和四周部分组成，中心部分包括一个或多个掺杂区域，四周部分为不掺杂区域。

7. 按照权利要求6所述的角泵浦固体激光增益模块，其特征在于：所述板条中心掺杂区域的横截面形状为长方形、正方形或圆形。

8. 按照权利要求4所述的角泵浦固体激光增益模块，其特征在于：所述板条的角面对泵浦波长镀增透膜。

9. 按照权利要求4所述的角泵浦固体激光增益模块，其特征在于：所述的板条的侧面对泵浦波长镀全反膜。

10. 按照权利要求4、5、6或7所述的角泵浦固体激光增益模块，其特征在于：激光入射面和出射面互成一定角度，且设置在板条的同一端。

11. 按照权利要求4、5、6或7所述的角泵浦固体激光增益模块，其特征在于：激光入射面和出射面互成一定角度，且设置在板条的同一端，在板条的另一端设置与入射面和出射面对称的两个端面，并在该两个端面的入射光路和反射光路上分别安装一个平面反射镜。

12. 按照权利要求4所述的角泵浦固体激光增益模块，其特征在于：所述的泵浦光源由二极管阵列和耦合装置组成，该耦合装置包括两个柱面透镜和一个导光镜，两个柱面透镜位于二极管阵列和导光镜之间，且彼此正交，分别平行于二极管的快轴和慢轴。

13. 按照权利要求4所述的角泵浦固体激光增益模块，其特征在于：所述的泵浦光源由二极管阵列和耦合装置组成，该耦合装置采用光纤束。

一种用于板条的角泵浦方法及其固体激光增益模块

技术领域

本发明涉及一种固体激光泵浦方法及固体激光增益模块，特别涉及一种具有板条结构的增益介质的泵浦方法及其固体激光增益模块，可应用于高功率固体激光器以及固体激光放大器中。

背景技术

在高功率固体激光装置中，一般采用棒状或者板条状的增益介质。板条状介质相对于棒状介质具有优势。例如，通过选择，使板条的材料具有相对高的折射率，冷却板条的介质则具有相对低的折射率，从而使激光光束在板条内部由于全反射而形成之字形光路。这种光路被称为之字形（Zig-Zag）光路。之字形光路匀化了板条厚度方向的光学不均匀性，降低了由此引起的热透镜效应，并且消除了应力引起的双折射效应。应用之字形光路的固体激光器专利包括：4，730，324；4，852，109；5，305，345；6，094，297；6，134，258等（美国）。

在固体激光增益模块中，目前现有技术中对增益介质进行泵浦一般采用以下几种方式：侧面泵浦方式、端面泵浦方式和边缘泵浦方式。在侧面泵浦结构中，泵浦光垂直于板条的轴线由侧面耦合到板条。具体来说，二极管阵列发出的泵浦光垂直于板条的轴线，从侧面耦合到板条，形成均匀的能量分布。采用这种结构的专利有：4，127，827；4，852，109；5，271，031；5，305，345；5，646，773；5，651，021等（美国）。由于结构限制，侧面泵浦的吸收长度只能有几个毫米。当这种侧面泵浦结构被用于低吸收系数固体激光材料的增益模块中，比如掺杂镱（Yb）的激光材料，就会导致低的吸收效率和低的总体效率。在专利6，094，297（美国）中，公开了一种新型的端面泵浦之字形光路的板条激光器，具有很长的吸收长度。但是这项发明的不利方面是：为了保持板条的厚度不致过大，无法将更多的泵浦光耦合到板条内部，这样就使得该激光器向高功率扩展较为困难。在专利6，134，258（美国）中，采用了横向的边缘泵浦结构，在板条的宽度方向而不是厚度方向吸收泵浦光，有效提高了吸收长度，但当采用吸收系数较低的增益介质时，这种结构无法得到较高的吸收效率。

对于采用准三能级材料的高功率激光器（例如 Yb:YAG 材料），为了降低激光阈值，掺杂浓度必须很低，从而导致吸收系数很低。在这种情况下，已有的泵浦结构其吸收效率不够充分。

发明内容

针对现有技术的不足和缺陷，本发明的目的是提供一种用于板条的角泵浦方法及其固体激光增益模块，使其具有长的吸收长度和高吸收效率，进而提高激光器的总体效率；并可达到更高的泵浦功率密度和更好的泵浦均匀性。当采用吸收系数较低的增益介质时，也

同样可以得到较高的吸收效率。

本发明的技术方案如下：

一种用于板条的角泵浦方法，该方法使泵浦光从板条的角部入射到板条内部。

板条角平面对泵浦波长高透，板条侧平面对泵浦波长高反；使激光光束在板条内的两个反射面之间沿着之字形光路传播。

本发明还提供了一种实施上述方法的角泵浦固体激光增益模块，该模块包括由固体激光材料构成的具有入射面和出射面的板条以及泵浦光源，其特征在于采用角泵浦结构，该结构是将泵浦光源放置在板条的角部位置，其泵浦光从板条的角部平面入射到板条内部。由于全内反射，大部分泵浦光被限制在板条内部进行多次吸收，从而提高了吸收效率。

为了达到更高的泵浦功率密度和更好的泵浦均匀性，降低板条四周的温度，使得本发明适用于准三能级的激光材料的激光器，本发明所用板条是由中心部分和四周部分组成，其中心部分包括一个或多个掺杂区域，四周部分为不掺杂区域。

本发明所采用的板条的角面对泵浦波长镀增透膜；板条的侧面对泵浦波长镀全反膜。

本发明与现有技术相比，具有以下优点及突出性进步：采用角泵浦方式及其结构，由于全内反射，可以使大部分泵浦光被限制在板条内部进行多次吸收，因而可以获得相当长的吸收长度和较高的吸收效率，从而提高激光器的总体效率。采用中心掺杂，四周键合不掺杂的复合材料，从而保证了泵浦光在板条中心被吸收，这种结构可以降低热透镜效应和应力双折射效应，减小板条四周的热量，避免板条的变形；更重要的是，能够达到更高的泵浦功率密度和更好的泵浦均匀性，对于低吸收系数的固体激光介质非常适用，例如 Yb 和 Tm。

附图说明

图 1 为本发明固体激光增益模块的总体结构图。

图 2a、2b、2c 为图 1 的 A-A 剖面，表示出板条形状的几种不同的具体实施例以及激光光路的传播方式。

图 3 为板条中心为掺杂区域，四周键合不掺杂区域的一个具体实施例的结构示意图。

图 4a、4b、4c 为图 3 的 B-B 剖面，分别表示板条每个掺杂区域的不同横截面。

图 6 为光纤耦合的角泵浦结构的示意图。

图 7 为本发明应用于主振荡器功率放大器中的结构示意图。

图 8 为本发明应用于振荡器中的结构示意图。

具体实施方式

下面结合附图进一步说明本发明的原理、结构及具体实施方式：

图 1 为本发明固体激光增益模块的总体结构图。增益模块 20 包括板条 22 和四个泵浦源 21。板条 22 的截面采用长方形或者正方形，具有相对的入射面 28 和出射面 30，四个侧面 31 和四个角面 32。角面不限于 4 个，也可以 8 个或更多。

板条 22 由高折射率的固体激光材料构成。由于全反射，入射光束 26 在板条内的两个

反射面之间沿着之字形光路传播，如图 2a 所示，这被称为之字形放大器。之字形放大器能够均化板条内部的温度梯度，使材料达到均匀增益。采用之字形光路、均匀泵浦、四角注入以及板条边缘的热绝缘，可以降低热透镜效应和应力双折射效应。

之字形光路可以具有各种不同的形式。如图 2a，板条 22 的入射面 26 和出射面 27 位于相反的两端；图 2b 中，板条 22 的入射面 61 和出射面 62 在同一端；在图 2c 中，板条 22 有四个端面 ，入射面 63 和出射面 64 也在同一端。在板条的另一端设置了与入射面和出射面对称的两个端面 65、66，并且安排了两个附加的反射镜面 70，该两个镜面分别安装在两个端面 65、66 的入射光路和反射光路上。图 2a, 2b, 2c 给出了之字形光路的几种不同形式，并没有描述出全部的可能。

为了实现高泵浦功率密度和均匀性，降低板条 22 四周的温度，板条 22 由复合材料键合而成（如图 1 所示）。板条 22 的四周部分 34 是不掺杂的材料，比如采用钇铝石榴石晶体（YAG）。四周部分 34 与板条 22 的中心部分 38 键合。中心部分 38 是掺杂的材料，比如：Yb:YAG，这样形成四个键合表面 40。这种键合工艺的具体描述可以参考专利 5，441，803（美国）。这种结构把泵浦光的吸收限制在板条 22 的中心部分 38，因此只有板条 22 的中心部分 38 产生热量，热量从四周部分 34 散发出去。为了使泵浦光更好的耦合到板条 22，四个角平面 32 可以对泵浦光束 24 镀增透膜。在图 1 中，相对的两个端面 28 和 30 对激光光束 26 镀增透膜，降低输入光束的损失。另外，四个侧面 31（上、下、左、右面）可以对泵浦波长镀全反膜，保证泵浦光束 24 不散逸出去。四束泵浦光束 24 从板条 22 的四个角平面 32 耦合到板条 22 内部，在板条 22 内部全反射，得到充分的吸收。通过使用上面所述的复合板条 22，泵浦光吸收部分被限制在板条的中心部分 38，从而得到相当高的泵浦功率密度和均匀性，适合准三能级的激光材料，例如：Yb 和 Tm。

板条 22 的中心部分可以包括一个或多个掺杂区域 39，图 3 示出了本发明的一个具体实施例，即板条的中心部分包括两个掺杂区域 39。通过附加的反射镜 71，使得激光光束在板条内部折叠通过各个掺杂区域。

掺杂区域 39 的横截面可以具有不同的形状，如图 4a, 4b, 4c 所示。掺杂区域 39 的横截面可以是长方形，正方形或者圆形。图 4a, 4b, 4c 只是给出掺杂区域 39 的几种截面形状，并没有描述出全部的可能。

泵浦光源 21 由高功率二极管阵列和耦合装置组成。高功率二极管阵列 56 由冷却器 57 冷却，产生泵浦光束。耦合装置的作用在于将二极管阵列发出的泵浦光高效率的耦合到泵浦面，并且得到尽可能高的如图 5，耦合装置 50 包括两个柱面透镜 52、53 和导光镜 54，导光镜放在二极管阵列 56 和板条 22 的角平面 32 之间；两个柱面透镜 52、53 被放置在二极管阵列 56 和导光镜之间，彼此正交，分别平行于二极管的快轴和慢轴。二极管阵列 56 由带有微透镜 60 的二极管条 58 堆叠而成。二极管条 58 的慢轴发散角为 8°，微透镜 60 将二极管条 58 的快轴发散角压缩为 3°。两个彼此正交的柱面透镜进一步压缩泵浦光的发散角，利于导光镜 54 进行大比例压缩。通过应用耦合装置 50，二极管阵列 56 的泵浦光被高

效的耦合泵浦到板条 22 的角平面上，并且可以得到较大的压缩比。例如，二极管阵列的尺寸是 2.7×2.2 厘米，而泵浦区域仅为 1×2 毫米。

耦合装置也可以为光纤束，如图 6 所示。采用由光纤 92 构成的光纤束 94 耦合泵浦光，可以得到同样的效果。为了简单起见，四个光纤束只画了一个。

采用本发明的增益模块 20 可以用于构成一个主振荡器功率放大器（MOPA），如图 7 所示。主振荡器 72 输出的种子光从端面 28 输入板条 22，主振荡器可以采用如图 8 所示的结构。

图 8 为利用本发明的增益模块 20 构成的主振荡器结构示意图。其中 76、84 为激光腔镜，分别为全反镜和部分反射镜。78 为调 Q 装置，80 为偏振片，86 表示出射激光。

在板条 22 内吸收泵浦光的区域温度会升高。为了冷却板条 22，可以采用不同的冷却方法，传导和对流冷却系统都是适合的。

为了减小板条 22 和制冷器之间的热阻，采用一层热传导层，由柔软的金属构成，比如铟层或者金层。装配时，需要加热制冷器/铟层/板条，例如 150℃，使铟层软化以消除接触阻抗。

在传导或者对流冷却中，板条 22 的上下表面是一层电介质材料作为倏逝波保护层 48，防止在全反射中倏逝波的能量泄漏，如图 2a 所示。倏逝波保护层 48 使板条 22 能够直接粘结在冲击制冷器上。MgF_2或 SiO_2层（厚度 2—4 微米）可以作为倏逝波保护层 48。

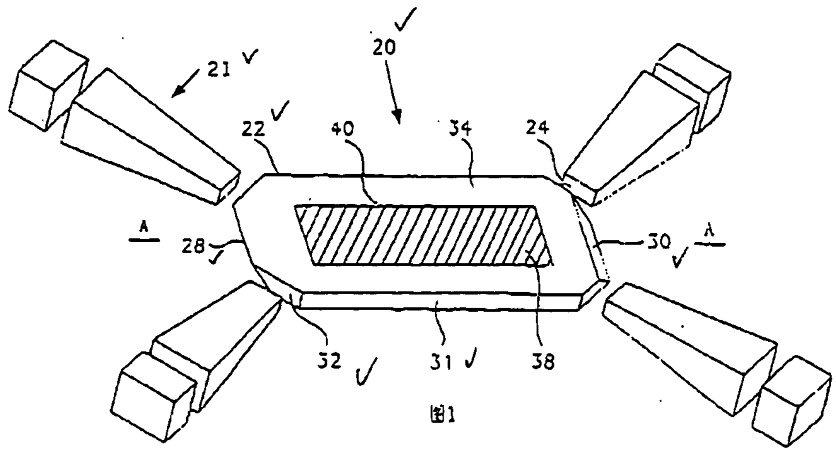


图1

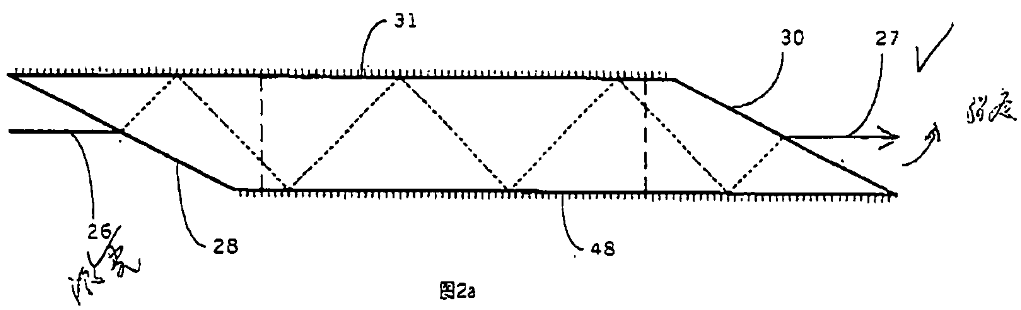


图2a

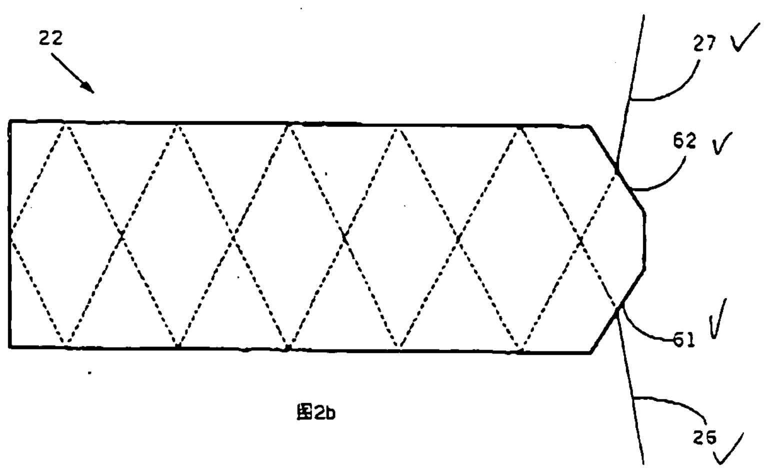


图2b

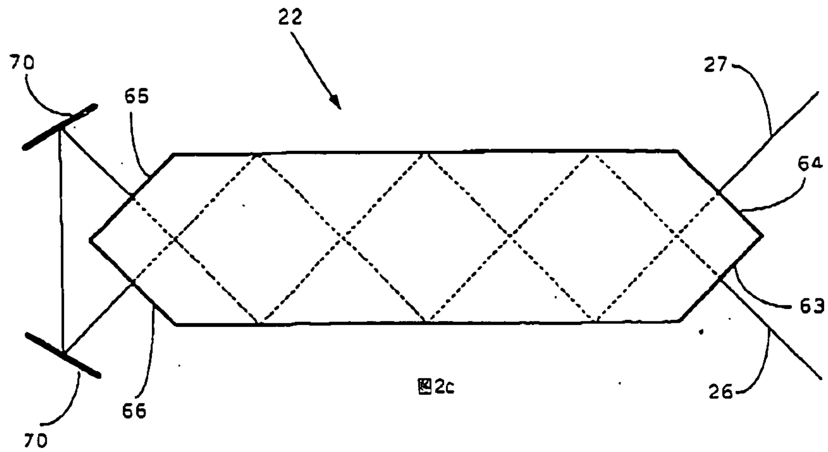


图2c

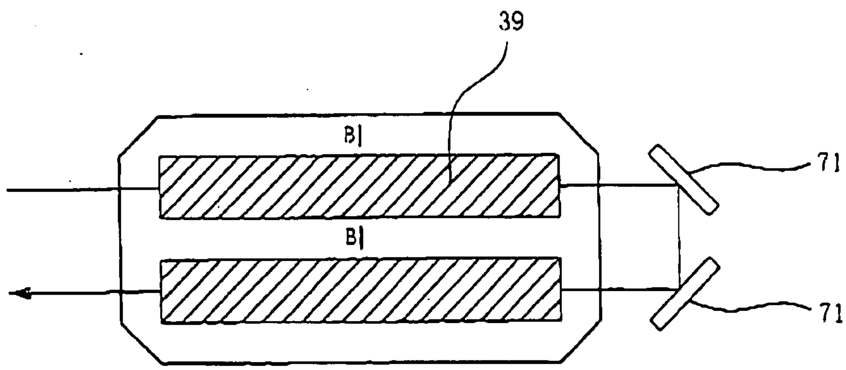


图3

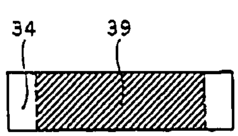


图4a

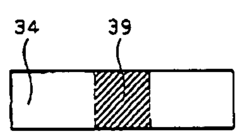


图4b

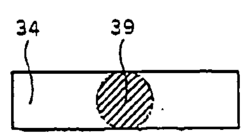


图4c

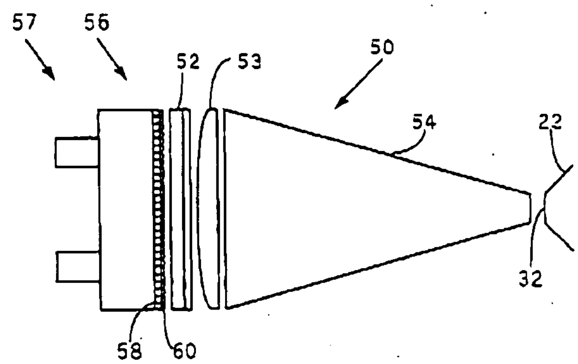


图5

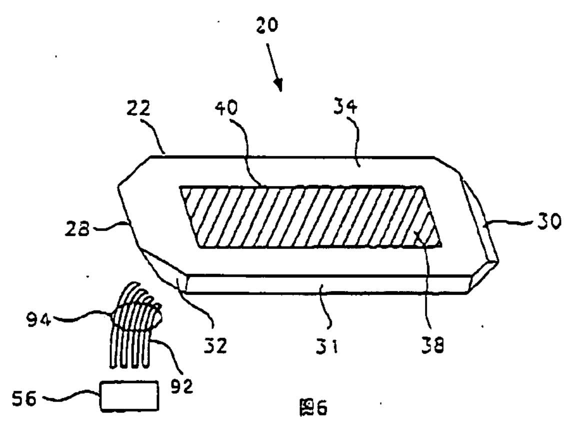
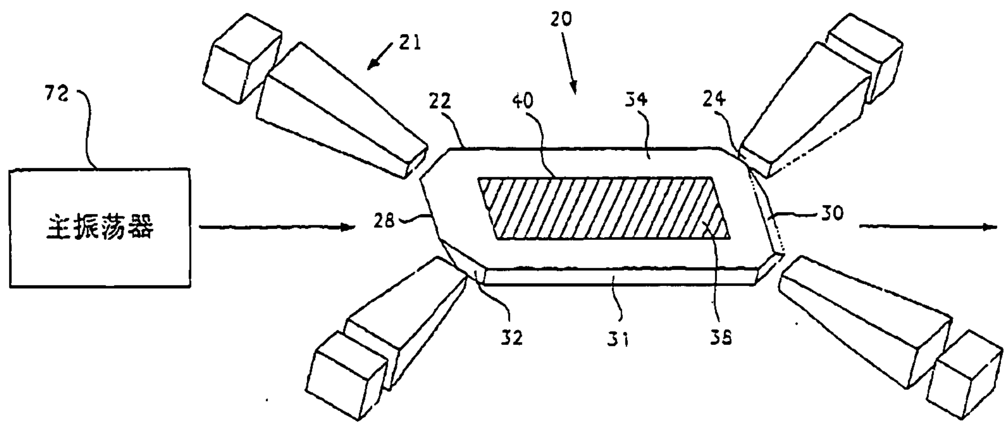
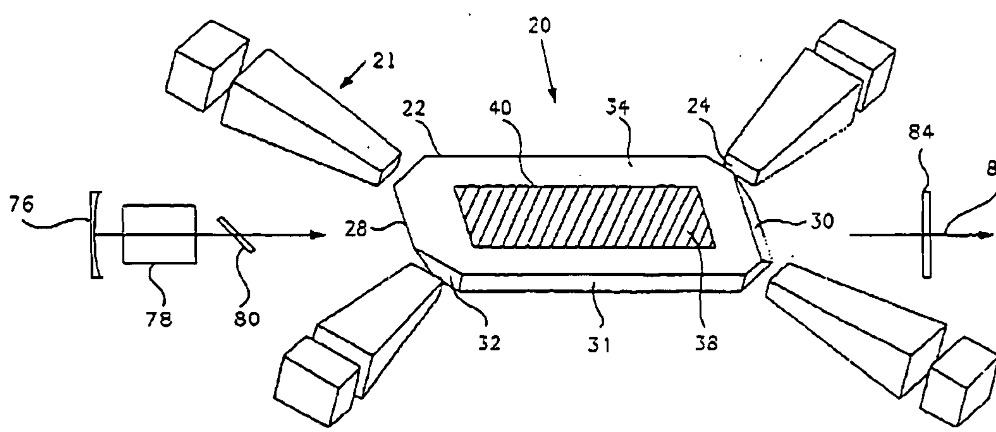


图6



主振荡器
72
21
20
22
40
34
24
28
30
32
31
38

图7



21
20
22
40
34
24
84
86
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28
30
78
80
32
31
38

图8

English Translation of Chinese Patent Application No: CN02129485.2

Title

Corner-Pumping Method and Gain Module for Solid-State Slab Lasers

ABSTRACT

A corner-pumping method and gain module for solid-state slab lasers. The pump source is placed near the slab corner, and the pump light is directed to the corner face and incidents inside the slab. In order to confine the absorption of the pumped light to the center portion of the slab, the circumambient portions of the slab may be undoped while the one or more center portions of the slab are doped. Light from the pump is incident into the slab and mostly confined in the slab by total internal reflections (TIR) in order to achieve fairly long absorption length and therefore high absorption efficiency, to get high overall efficiency of the slab laser. This arrangement reduces the thermal distortions of the slab and the thermal induced effects, such as thermal lensing and birefregence, by the zig-zag path. More importantly, it offers high pump power density and good pump uniformity. This corner-pumping method is particularly suitable for solid-state laser medium with relative low absorption coefficient. This invention may be used in either a laser or an optical amplifier.

What is claimed is:

1. A corner-pumping method for slab lasers wherein said pumping method allows the pump light incident into the laser slab through the slab corners.

2. The pumping method as recited in claim 1, wherein corner faces are coated for high transmission at the wavelength of the pump beams, lateral faces are coated for high reflection at the wavelength of the pump beams.

3. The pumping method as recited in claim 1 or 2, wherein the laser beam propagates inside the slab between two TIR faces in a zig-zag optical path.

4. A solid-state laser gain module utilizing the pumping method as recited in claim 1, consists of a slab of a solid state lasing material with input and output faces and the pump source, wherein corner-pumping geometry is used. The pump source is placed near the slab corner, and the pumped light is directed into the corner faces of the slab.

5. The corner-pumped solid-state laser gain module as recited in claim 4, wherein said slab has four corner faces.

6. The corner-pumped solid-state laser gain module as recited in claim 4, wherein said slab is formed by circumambient portion and central portion. The circumambient portion of the slab is formed from an undoped host material while one or more center portions of the slab are formed from doped host material.

7. The corner-pumped solid-state laser gain module as recited in claim 6, wherein the cross section of the said central portion is rectangular, square or circular.

8. The corner-pumped solid-state laser gain module as recited in claim 4, wherein said corner faces are anti-reflection coated at the pump wavelength.

9. The corner-pumped solid-state laser gain module as recited in claim 4, wherein said lateral faces are high-reflection coated at the pump wavelength.

10. The corner-pumped solid-state laser gain module as recited in claim 4,5,6,7, wherein input face and output face of the laser beam are at the same side of the said slab.

11. The corner-pumped solid-state laser gain module as recited in claim 4,5,6,7, wherein input face and output face of the laser beam are at the same side of the said slab. Two additional mirrors are placed at the opposite side of the said slab.

12. The corner-pumped solid-state laser gain module as recited in claim 4, wherein said pump source consists of diode array and coupling system. The coupling system includes two cylindrical lens and a lens duct. The two cylindrical lenses, placed between the diode array and the lens duct, are orthogonal to each other, and parallel to diode array's fast axis and slow axis, respectively.

13. The corner-pumped solid-state laser gain module as recited in claim 4, wherein said pump source consists of diode array and coupling system, the said coupling system is fiber bundle.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to a pumping method and gain module for use, for example, in a high power solid state laser and more particularly to a pumping method and gain module which includes an extended slab of a solid state lasing material, for example, a rare earth doped yttrium-aluminum-garnet (YAG) crystal. This invention may be used in either a laser or an optical amplifier.

2. Description of the Prior Art

For high power solid-state lasers, gain medium with rod or slab geometrics are commonly used. In general, slab geometry has advantages over rod geometry. For example, material for the slab is selected to have a relatively high index of refraction. The slab is cooled with a cooling medium having a relatively low index of refraction. This change in the index of refraction at the slab coolant interface results in incident light beams directed to one end face of the slab being totally internally reflected through the slab in a zig-zag manner. The zig-zag optical path averages the primary thermal gradient in the thickness direction, reduces thermal lensing effect. The rectilinear cross section of the slab makes stress-induced birefringence much lower. Example of solid state lasers utilizing such zig-zag amplifiers are disclosed in U.S. Pat, Nos.: 4,730,324; 4,852,109; 5,305,345; 6,094,297 and 6,134,258.

In order to excite the laser slab to a relatively high energy metastable state. various pumping methods have been developed, such as side-pumping, end-pumping, and edge-pumping. For side-pumping geometry, the pumping sources are configured such that the light from the pumping source is directed along a lateral face of the slab in a direction generally perpendicular to the longitudinal axis of the slab, to obtain uniform pump power distribution in the slab. Examples of optical amplifiers with such a configuration are disclosed in U.S. Pat. Nos.: 4,127,827; 4,852,109; 5,271,031; 5,305,345; 5,646,773 and 5,651,021. Such configurations, unfortunately limit the absorption length of the pumping light to just a few millimeters. When such side pump configuration are used with optical amplifiers which use a solid state lasing material with relatively low absorption coefficient, such as Yb doped materials, low absorption efficiency, and thus lower overall efficiency results. Disclosed in U.S. Pat. No. 6,094,297, a novel end-pumped zig-zag slab laser which has relatively long absorption length is invented, but the disadvantage of this invention is that, with such configuration, power scaling is difficult because one can not couple more pump power into the slab while maintaining the slab thickness not too large. Disclosed in U.S. Pat. No. 6,134,258, a transverse-pumped configuration is invented in order to increase absorption length by using width of the slab instead of thickness to absorb pump light. Unfortunately, for high power laser using quasi-three level lasing material, such as Yb:YAG, the doping concentration must be low in order to decrease lasing threshold, therefore. absorption is not sufficient while utilizing such transverse-pumped configuration due to relatively low absorption coefficient.

SUMMARY OF THE INVENTION

The present invention provides a corner pumping method and gain module for use, for example, in a high power solid state slab laser, in order to obtain a relatively increased absorption length and higher absorption efficiency, therefore to get high overall efficiency. The corner-pumping geometry also provides high pump power density and good pump uniformity. When applied for laser medium with low absorption coefficient, it can also provide relatively high absorption efficiency.

The invention mainly includes the following aspects.

A corner-pumping method for slab lasers in which the pump light is directed to the corner face and incidents inside the slab.

The corner faces of the slab are coated with anti-reflection coatings at the pump wavelength. The lateral faces of the slab may be high-reflection coated at the pump wavelength in order to ensure pump light not to escape. Laser beam propagates inside the slab between two TIR faces in a zig-zag optical path.

This invention also provides a solid-state laser gain module utilizing the above corner-pumping method. The gain module consists of a slab of a solid state lasing material and the pump source. The slabs are formed with a generally rectangular or square cross section area defining an input face and an output face. The gain module in accordance with the present invention incorporates corner pumping in which the pumped light is directed into the corner faces of the slab and mostly confined by total internal reflections (TIR) resulting in multiple absorptions and high absorption efficiency.

In order to obtain higher pump power density and better pump uniformity as well as reduce the circumambient temperature of the slab, to make this invention suitable for quasi-three-level laser medium, the slab is formed from a composite material with the circumambient portions of the slab formed from an undoped host material while one or more center portions of the slab are formed from doped host material.

The laser slab in accordance with the present invention has the following coatings. The corner faces are anti-reflection coated at the pump wavelength, the lateral faces are high-reflection coated at the pump wavelength.

The present invention has the following advantages compared to those former inventions. Use of corner pumping in which the pumped light is directed into the corner faces of the slab and mostly confined by total internal reflections (TIR) resulting in multiple absorptions and high absorption efficiency, therefore enhance the overall efficiency. Use of composite material with the circumambient portions of the slab formed from an undoped host material while one or more center portions of the slab are formed from doped host material, to ensure that the pump power is absorbed in the center portion of the slab. Such a configuration provides relatively low residual thermal lensing, virtually no birefringence, reduced circumambient temperature and distortion of the slab, and more importantly, higher pump intensity and better pump uniformity for quasi-three level lasing material, such as Yb and Tm.

DESCRIPTION OF THE DRAWINGS

The principles of the present invention may be readily understood with reference to the following specification and attached drawing wherein:

Fig.1 is a whole view of a gain module in accordance with the present invention.

Fig.2a,2b,2c are A-A cross section views of Fig.1, show alternative shapes for the laser slab and alternative optical path for the laser beam.

Fig.3 shows an alternative embodiment of the invention illustrating a slab with two center doped portions.

Fig.4a, 4b. and 4c are B-B cross-section views of Fig.3, describe alternative shapes of the doped host material.

Fig.5 is a diagram of a lens duct assembly and diode array for use with the present invention.

Fig.6 is a plan view of an alternate embodiment of the invention illustrating a corner pumped architecture with fiber coupled pump light.

Fig.7 is a schematic diagram of the corner pumped gain module in accordance with the present invention in a master oscillator power amplifier (MOPA) configuration.

Fig.8 is similar to Fig.7 where the gain module in accordance with the present invention is used in a resonator configuration.

DETAILED DESCRIPTION

Fig.1 is a whole view of a gain module in accordance with the present invention. The gain module 20 includes a slab 22 and four pumped beam sources 21. The slab 22 is formed with a generally rectangular or square cross section defining a pair of opposing end faces 28 and 30, four lateral faces 31 and four corner faces 32. The number of corner faces is not restricted to be only four, more corner faces are also feasible.

The slab 22 may be formed from a solid state lasing material with a relatively high index of refraction to cause internal reflection of the input beam 26 in a generally zig-zag pattern as illustrated in Fig.2a, forming a so called zig-zag amplifier. Such zig-zag amplifiers are known to allow the input beam to average thermal gradients in the slab effectively providing a homogeneous gain medium. Zig-zag optical path, homogeneous four corners pumping, and thermal insulation at the slab edges can reduce thermal lensing as well as stress Induced birefringence.

There are many alternative forms for the zig-zag optical path. In Fig.2a, the input face 26 and output face 27 are located at the opposite ends of the slab 22. In Fig.2b, input face 61 and output face 62 are at the same side of the slab 22, rather than at opposite sides as in Fig.1b. In Fig.2c, slab 22 has four end faces 63, 64, 65, 66. Input face 63 and output face 64 are at the same side of the slab 22. Two additional mirrors 70 are used in this arrangement, and are placed in the input optical path of face 65 and the output optical path of face 66. Fig.2a, 2b, 2c are intended to give an idea of the variety of shapes possible for slab 22. The figures do not represent an exhaustive list.

In order to get higher pump power density and better pump uniformity, and reduce heating of the circumambient portions of the slab 22, the slab 22 is formed as a diffusion bonded composite material (see Fig.1). More particularly, around the slab 22, the circumambient portions 34 of the slab 22 can be form from undoped host materials, such as yttrium-aluminum-garnet (YAG). These

circumambient portion 34 can be diffusion bonded to a central protion 38 of the slab 22 formed from a doped host material, such as Yb doped YAG (Yb:YAG) forming four diffusion bond interfaces 40. Such diffusion bonding techniques are known in the art, for example, as described in detail in U.S. Pat. No. 5,441,803 hereby incorporated by reference. Such a configuration limits the pump power absorption to the center portion 38 of the slab 22. By limiting the pump power absorption to the center portion 38 of the slab 22, heat generated by the optical pumping is in the center portion 38 and away from the circumambient portion 34. In order to enable the pump light into the slab 22, the four corner faces 32 may be formed by way of a coating, such as an antireflection coating selected for the wavelength of the pump beams 24. As shown in Fig.1, the antireflection coating selected for the wavelength of the laser beam 26 is disposed on the opposing end faces 28 and 30, and thereby reducing losses of the input laser beam. Furthermore, four lateral faces 31 are high-reflection coated selected for the wavelength of the pump beams 24 to ensure pump light not to escape. The four pump beams 24 are directed to four corner faces 32 of the slab 22 and are totally reflected inside the slab 22 to achieve sufficient absorption. By utilizing the composite slab 22 as discussed above, the pump power absorption of the slab 22 is limited to the central portion 38 and therefore results in relative high pump power density and good pump uniformity which is particularly profitable for quasi-three level lasing material, such as Yb and Tm.

An alternate embodiment is illustrated in Fig.3. This embodiment is essentially the same as the embodiment illustrated in Fig.1 with the exception that there are two doped host materials 39 and therefore the optical path is folded by the additional mirror 71.

There are many alternative shapes for the doped host material 39, Fig4a, 4b, and 4c show that the cross-section of the doped host material 39 can be rectangular, square or circular. Fig.4a, 4b, 4c are intended to give an idea of the variety of shapes possible for doped host material 39. The figures do not represent an exhaustive list.

The pump source 21 consists of high power diode array and its coupling system. High power diode array 56, for example, with a diode array cooler 57, may be used to generate the pump beams. The coupling system is aimed to couple the pump light from high power diode array to the pump face efficiently, as generally illustrated in Fig.5. The coupling system 50 includes two cylindrical lens 52, 53 and a lens duct 54, placed between a diode array 56 and a corner face 32 on the slab 22. The two cylindrical lenses are orthogonal to each other, and parallel to diode array's fast axis and slow axis, respectively. The diode arrays 56 may include a plurality of stacked diode bars 58 with individual micro-lens 60. The micro-lens 60 reduce the divergence of the fast axis of the bars 58 approximate 3° while the slow axis may have a full angle divergence on the order of 8°. By using the lens duct assembly 50, the output of the diode array 56 can be efficiently imaged onto the corner faces of the slab 22 with a large compress ratio, such that a 2.7×2.2cm diode array may be imaged onto an area as small as 1×2mm.

An alternate embodiment is illustrated in Fig.6. This embodiment is essentially the same as the embodiment illustrated in Fig.1 with the exception that the pump light is coupled to the slab 22 by one or more optical fibers 92 forming a fiber bundle 94. Only one of four fiber bundles is shown for brevity.

The gain module 20 in accordance with the present invention may be used to form a master oscillator power amplifier (MOPA). In this embodiment as illustrated in Fig.7, a master oscillator 72 is directed to an input end face 28 of the slab 22. The master oscillator may be, for example, as

discussed and illustrated with respect to Fig.8 below.

As illustrated in Fig.8, the optical amplifier 20 may be used to form a master oscillator 74. Inside, 76 and 84 are high reflective and partial reflective cavity mirrors, respectively. 78 is the Q-switch, 80 is the polarizer, and 86 represents output laser beam.

It is known in the art that pumping of the slab 22 results in increased temperature in the area where the pump light is absorbed. In order to cool the slab 22, various cooling methods can be used. Both conduction and convection cooling systems are suitable.

To minimize the thermal resistance between the slab 22 and the coolers, a thin layer of a thermally conductive material such as a soft metal, such as indium or gold, may be used. During assembly, the cooler/indium/slab assembly may be held under pressure at elevated temperatures, approximately 150℃ to flow the indium and eliminate contact resistance.

In the case of convection and conduction cooling, the upper and lower faces of the slab 22 are coated with a dielectric material which serves as an evanescent wave coating 48 to preserve total internal reflection, as shown in Fig.2a. The evanescent wave coating 48 allows the slab 22 to be in directly adhered to the impingement cooler. A thick layer (2-4μm) of MgF_2 or SiO_2 may be used as the evanescent wave coating 48.

Obviously, many modifications and variations of the present invention are possible in light of the above teachings. Thus, it is to be understood that, within the scope of the appended claims, the invention may be practiced otherwise than as specifically described above.

Figures

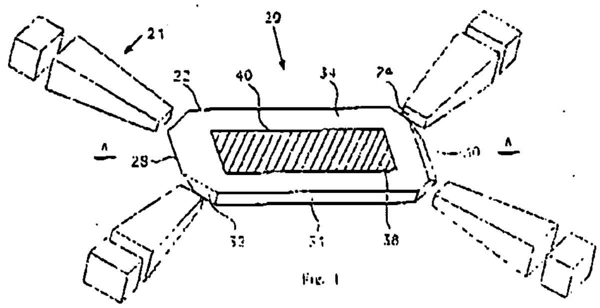

Fig. 1

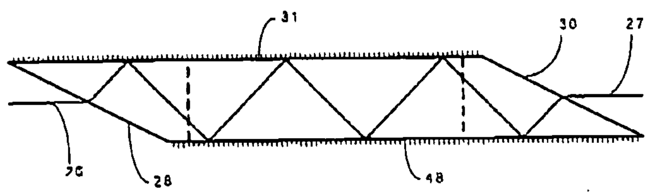

Fig. 2a

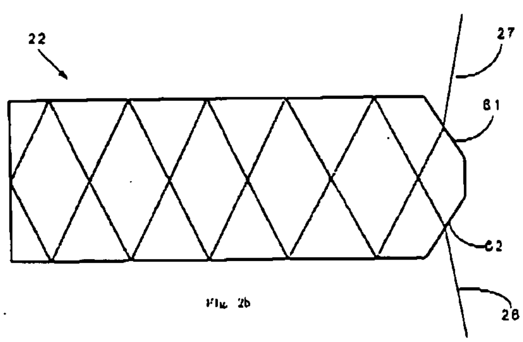

Fig. 2b

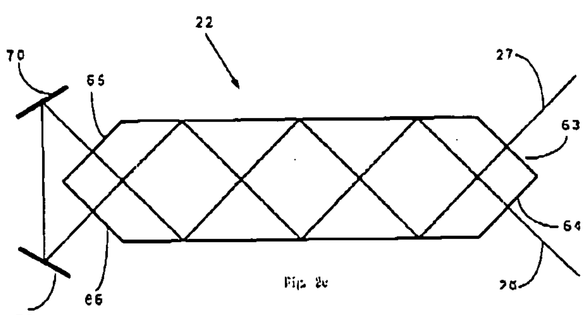

Fig. 2c

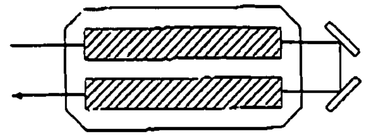

Fig. 3

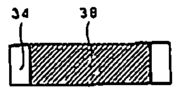

Fig. 4a

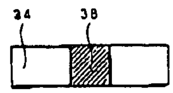

Fig. 4b

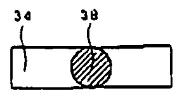

Fig. 4c

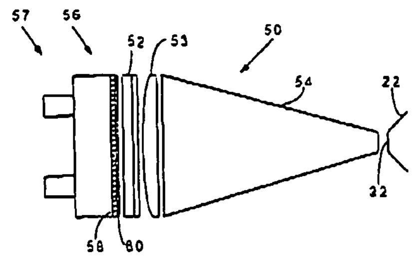

Fig. 5

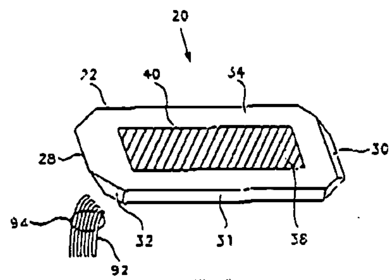

Fig. 6

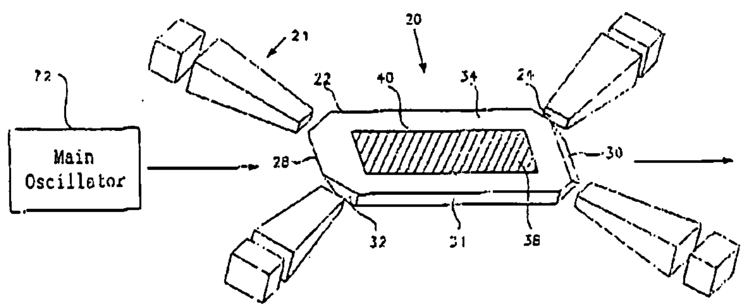

Fig. 7

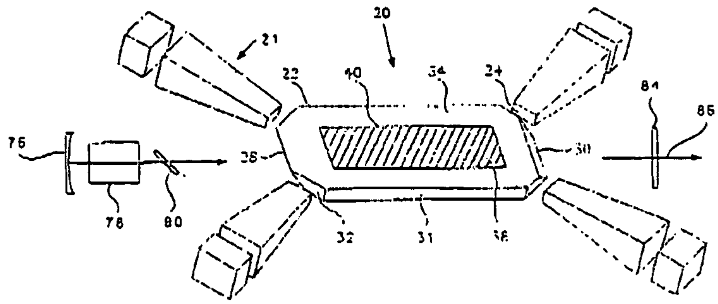

Fig. 8